

Study Committee D1 Materials and Emerging Test Techniques

Paper D1-PS2-11109

COMPATIBILITY OF TRANSFORMER MATERIALS WITH INSULATING LIQUIDS

Ivanka ATANASOVA-HÖHLEIN*, V. HARAMIJA, D. VRSALJKO

Siemens Energy*, Končar - Electrical Engineering Institute

Motivation

- Material incompatibility can have different demonstrations in service, e.g., leakages in case of gaskets as well as electrical and/or mechanical breakdown or /and oil parameter influence.
- The aim of this study is a proposal for the testing ratios of materials with insulating liquids, as well as limit acceptable values for those materials. This experience is based on a long-term experience of a big transformer manufacturer.

Method/Approach

- Methods shall include testing both - the influence of the liquid on the material as well as vice versa – the impact of the material on the liquid.

Recommendations for ratios of different materials to the corresponding insulating liquid, as well as test duration, type of test and temperatures are given.

In all cases it is important to evaluate the difference between the blank reference sample (i.e., aged liquid without the material) and the sample with the material. The testing procedure is as following:

- Testing of the dry insulating liquid in original state, Remark: breakdown voltage shall be not below 50kV/2,5 mm. All properties shall be according the corresponding standards in the delivery state.
- Drying of the tested material for 48h at 105°C in vacuum $\leq 0,1$ mm.
- Preparation of the material in the insulating liquid in the desired ratio in flexible bottles, e.g., made of aluminium; filling the bottles with the corresponding liquid considering its expansion coefficient at the temperature of storage.
- Flushing with dry nitrogen for 10 min and tightly sealing the bottles with screw caps.
- Heating in oven at the desired temperature.
- Cooling down to room temperature.
- Performing the tests on the liquid and the material.

Requirements for compatibility testing

The requirement for durability of different materials in a transformer application may be quite different, depending on its type, design, and type of insulating liquid. It is necessary to know, whether the material will be used in the winding, e.g., enameled wire and thus will experience hot spot temperatures or only in the bulk oil. It is important to know what are the mechanical requirements concerning tensile or bending strength or long-term adhesion properties. For specific important mechanical requirements long term ageing additional to the short-term compatibility test will be necessary in order to evaluate their change over time.

- For the test of compatibility, it is essential to estimate which is the targeted application – conventional or high temperature, in which liquid, what is the area affected, what are the mechanical properties affected. Since thermal gradients exist in all transformers, even in transformers with high temperature hybrid insulation, some conventional materials are acceptable in locations whether conventional temperatures are maintained.
- Liquid insulated transformers are monitored off- or on-line by means of effective procedures like dissolved gas analysis (DGA), which is able to predict the condition of the electrical equipment as such. The insulating liquid parameters give information on the insulation condition and ageing status of the insulating liquid. These procedures are mature and described in numerous IEC and ASTM standards. In the existing compatibility standards, however, only the insulating liquid properties are concerned, but not the gas-in-oil analysis. For materials with a high area of application like the internal coating of transformers or similar equipment, it is very important to know the gassing behaviour of the varnish, since some gases may interfere with the known interpretation schemes of gas-in-oil analysis in service and may indicate a potential fault.

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Recommendations for ratios of different materials/corresponding insulating liquid, as well as test duration, type of test and test temperature

Material	Recommended ratio material/insulating liquid cm ³ /l	Insulating liquid values		Gas-in-oil analysis Temperature (°C) mineral oil/ester or silicone	Test on the material itself
		Temperature (°C) mineral oil/ester or silicone	Duration 7 days		
Internal varnish	500	105/130		80/105	-
Sealing material	65	105/130		-	Compression set, hardness, weight change, volume change
Enameled wire	[10]	150/160		-	Breakdown voltage
Auxiliary materials, e.g. adhesives, screw locking etc.	6.5	105/130		80/105	Adhesive strength in comparison to original state
Insulating material with mechanical requirements	50	105/130		80/105	Degree of polymerisation tensile strength, bending strength

In case of new type of materials, a long-term compatibility test (e.g. 7 weeks test) is generally recommended with a consequent testing of the material properties.

Recommendation for tests on the liquid insulation

The tests on the liquid insulation shall be done by evaluation of the comparison between properties of the pure liquid aged (blank sample) and the liquid aged with the material under the same conditions. Following properties shall be investigated: colour, appearance, acidity, dissipation factor, breakdown voltage, interfacial tension. In some cases also other properties like water content (especially in liquids prone to hydrolysis), fire point, corrosive sulfur etc. can be of importance.

Recommendation for tests on the material

The tests on the material tested for compatibility shall be done according to the design requirements. Some of the tests are described in the corresponding IEC standards. If this is not the case, the functional requirements for the corresponding materials must be considered. Some examples are given below:

• Enameled wire

Suitable tests are the elasticity test of the enamel insulation. The bending point must be smooth, without delamination and cracks. A very important test is the breakdown voltage of the aged wire, which is a functional test for the dielectric withstand of the insulation.

• Gaskets

Example for the testing procedure of a nitrile butadiene rubber (NBR) O-ring under mineral oil for transformer application is given below :

Tests under delivery conditions

- A-Hardness
- Density

Tests on the O-Ring after storage (105°C) under mineral Oil

- Volume and weight change
- Dimension change
- A-Hardness Change
- Compression set
- Cold Resistance

Tests on the mineral oil after storage (105°C) with the O-ring

- Colour/appearance
- Acidity
- Interfacial tension
- Dielectric dissipation factor (DDF) at 90 °C
- Breakdown voltage

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Discussion

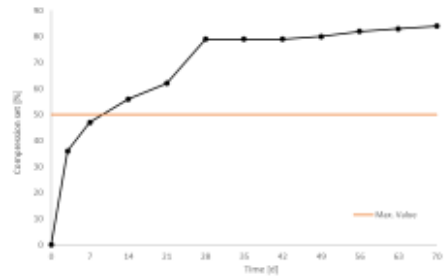
Recommendations for gasket test values after compatibility testing for nitrile butadiene rubber

Material identification	Hardness change Shore-Hardness A	Weight change (%)	Volume change (%)
NBR (nitrile butadiene rubber)	-8 to 0	0 to +10	0 to +15

- Increase in hardness after ageing means increase in rigidity of the gasket and is not acceptable. On the other hand, increase in volume contributes to better sealing properties, especially in case of O-rings.
- For compression set testing the test specimen is pressed in its original state between flat metal plates until a reduction in the initial thickness of 30% for panels is achieved. After the required test duration of the storage in the corresponding insulating liquid, temperature and time, the compression set assembly is removed from the oven and cooled to the standard laboratory temperature. The test pieces are released from the clamp and visually assessed. No breaks or cracks shall be visible. After a period of 2 hours, the compression is measured and the compression set is calculated. The value shall not exceed 50%.



Cracking in a round enameled wire after a compatibility test.



Progress of the compression set with time of an incompatible in mineral oil gasket.

Examples of material incompatibility encountered by testing



Material changes in an incompatible gasket, causing leakage.

Conclusion

- Compatibility of construction material in liquid filled transformers and similar electrical equipment must be tested in order to ensure its compatibility and exclude problems in service.
- The compatibility testing after ageing must be done not only in the insulating liquid but also on the material. The selected properties shall be oriented to corresponding standards or to required design values. In certain cases, long term testing next to the usual short term testing can be necessary. Additionally to the liquid insulation values, the gassing behaviour of the construction material shall be tested, in order to prevent interference with applied diagnostic criteria for DGA.